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DEVELOPMENT OF A SYSTEMATIC
TECHNIQUE FOR ANALYZING THE
EFFECTIVENESS OF AIRCRAFT
CLASS IV MODIFICATIONS

Charlie J. Coleman, Jr., Major, USAF
Thomas R. Edison, Captain, USAF

LSSR 10-78B

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This study uses data from the Air Force Maintenance Requirements Data System (G098) to develop an assessment technique which uses parametric and nonparametric statistical mean difference tests to evaluate the effectiveness of Class IV modifications. Fourteen selected modifications were evaluated to demonstrate how the G098 data were compiled and analyzed by this technique. Included in this evaluation were data on maintenance actions, manhours, NORM, NORS, and failures before and after the modification. These data sets were adjusted for variations in flying hours and sorties. The data were then analyzed to determine if there were any significant improvements as a result of the Class IV modification. A modification was determined to be effective if these improvements were part of the original stated purpose of the modification as indicated on the AFLC Form 48. The results of the study indicated that a systematic assessment technique which uses existing data could be developed.

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By

(10) Charlie J./Coleman, Jr. [redacted] Thomas R./Edison/ BS

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This thesis, written by

Major Charlie J. Coleman, Jr.

and

Captain Thomas R. Edison

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(ACQUISITION LOGISTICS MAJOR)
(Major Charlie J. Coleman, Jr.)

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(Captain Thomas R. Edison)

Date: 8 September 1978

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INTRODUCTION

As stated in Air Force Manual 1-1, the Air Force's role in national defense is to organize, train, and equip its forces for conduct of prompt and sustained aerospace operations essential to the effective prosecution of war (27:2-3). A shortage of available weapon systems would severely hamper the Air Force's ability to perform its designated national defense role and decrease our nation's military combat readiness (17:25).

In 1976, Gansler, then Deputy Assistant Secretary of Defense for Material Acquisition, stated that the Department of Defense (DOD) has recognized the need for knowing what parameters should be designed into new weapon systems to increase their availability while decreasing their logistic support requirements (10:1). He emphasized that the DOD has given considerable attention to improving availability by designing more reliable and maintainable equipment into its new weapon systems. DOD is concerned when inadequate equipment reliability and poor maintainability design cause aircraft to be grounded, to fly in a degraded condition, or to be unavailable for the full combat mission for which procured (10:1).

Efforts have been made by the Air Force to foresee and design for problems that would be encountered during the operational life of its weapon systems. Reliability and maintainability have been and continue to be highlighted during the design of newer Air Force weapon systems. The F-15 aircraft, for example, has been designed with a high reliability parts program and a stringent test effort to provide maximum equipment reliability and maintainability (16:40). As Gansler stressed, Air Force test programs should incorporate the flexibility to permit attainment of a proper balance of logistic support requirements and performance requirements. Hardware must be designed to emphasize simple, rugged, and easily maintained designs. However, as Gansler further emphasized, such an approach requires funds and schedules for design flexibility. Managers, both in the Government and in private industry, should plan their programs to accommodate these requirements so as to achieve low-cost, simple, highly reliable and maintainable weapon system designs (10:1).

Imperfect foresight and use of systems beyond their initially expected life have contributed to deficiencies being identified after the system has become operational (11:1). While every attempt is made to initially design equipment reliability and maintainability into the weapon system equipment, deficiencies are often not discovered until after the weapon system has entered the inventory and

production has ceased. Changes made to correct these deficiencies are called modifications (11:1).

MODIFICATIONS

Only recently has the Air Force emphasized that reliability be designed into new weapon systems. Former Deputy Secretary of Defense Clements on February 28, 1976, issued a memorandum to the Secretaries of the Military Departments that tasked them to develop weapons that cost less to operate and support by designing in greater equipment reliability and maintainability (22:1). Another significant area for reducing O&S costs is in existing Air Force in-inventory aircraft. The Air Force has many aging weapon systems in its inventory. For example, the F-4 aircraft entered the Air Force inventory in FY 63 and the F-111 aircraft in FY 66 (6:3).

Although the Air Force is faced with aging weapon systems which possess equipment that lack the current "state-of-the-art" improvements, budgetary constraints have restricted the funds available for accomplishment of modifications. Therefore, as Shrontz, former Assistant Secretary of Defense for Installation and Logistics, stated:

> . . . approval of modifications has become more stringently controlled so that the greatest benefits possible in terms of improved reliability and maintainability can be obtained [22:1].

He emphasized that the Department of Defense must be highly

critical of approving a specific modification and must insure that the modification will produce the maximum improvement to aircraft availability, i.e., improve equipment reliability and reduce manhours required for support.

Modification of in-use systems is a very expensive proposition. Indeed, the Deputy Chief of Naval Material for Reliability and Maintainability has stated that ". . . field retrofit to correct poor design is the most expensive and disruptive approach to reliability improvement [34:16]." Since modifications are so costly and critical to systems improvement, the Air Force published Air Force Regulation (AFR) 57-4 which provides guidance for justifying, submitting, approving, and accomplishing modifications. There are several classes of modifications. The basis of classification is the nature of the change or the degree of improvement (28:10-11). Each of the classes can be defined as follows:

Class I. A temporary change to accomplish a special mission for a special purpose.

Class II. A temporary means to support research and development or operational test and evaluation programs.

Class III. Required to attain production continuity.

Class IV. Required to correct an observed material deficiency; this class of modification is divided into three subclasses:

1. Class IVA. Required to insure safety of personnel, systems, or equipment by eliminating operational, nuclear, or physical hazard and if uncorrected, the hazard would ground the system or equipment, restrict flight or ground operations, or result in unacceptable risk to personnel [28:10].

2. Class IVB. Required to correct a deficiency including one that affects reliability and maintainability and if uncorrected the deficiency would cause mission failures, impede the system or equipment mission accomplishment of other systems or equipment within the defense or civilian community [28:10].

3. Class IVC. Required for logistic support purposes and one of the following benefits will result: significant improvement in maintainability or service life; improved logistic support by modification of present equipment in lieu of procurement; reduce costs by standardizing equipment configuration [28:11].

Class V. Required to satisfy a requirement for a new capability which constitutes a change in mission.

CLASS IV MODIFICATION PROCESS

The Class IV modification process is generally initiated by a reported deficiency from an operating unit. The report of a deficiency may take several forms. The first of these are the Incident Report and Emergency Unsatisfactory Material Report which are submitted by the operating unit directly to the responsible Air Logistics Center (ALC). The second is the Modification Proposal which is submitted through channels to the responsible Air Logistic Center (6:26).

In a briefing at a 1977 conference at Wright-Patterson AFB (29:7), it was emphasized that the responsible Air Logistics Center System Management or Item Management Division must evaluate the reported deficiency through establishment of a Material Improvement Project. After evaluation in the responsible System or Item Management Division, the Material Improvement Project is forwarded to the Service Engineering Division for an engineering analysis. If a modification is the only means by which the deficiency can be eliminated, the Service Engineering Division develops the complete engineering solution.

When the deficiency is initially reported by a command modification proposal, the modification proposal is reviewed in detail by base-level and major command logistics managers prior to its being forwarded to the Air Logistics Center for approval (28:13).

Once the engineering solution to the deficiency has been determined, the System Manager or Item Manager obtains coordination or certification from the using commands and other involved agencies. The certification process involves Configuration Control Board (CCB) review of the engineering solution (6:33).

AFR 57-4 requires that each major command establish a CCB which is responsible for reviewing all modification proposals originating in or which affect the command (28:4-7). The review must provide certification that the

modification is required and must include a statement of the benefits and impact for approval of the modification.

There are also CCBs at the Air Logistic Centers, Air Force Logistic Command (AFLC) Headquarters, and at the Air Staff (6:33). The ALC boards consider all proposed modifications that have a total cost of less than $500,000 (33). If the total cost exceeds $500,000 and the ALC recommends approval, the proposed modification is forwarded to the AFLC board for approval. However, if the total cost of the proposed modification exceeds $5 million then the Air Staff must approve it. Each board tries to obtain the maximum overall benefit for the Air Force. The AFLC board, however, decides how the majority of the Air Force modification dollars will be spent (33).

The review of a modification proposal by a CCB is accomplished by reviewing the AFLC Form 48 (Configuration Control Board Item Record) as discussed by Baker et al. in their study (2:26). This form is completed by the System Manager and describes the technical and cost characteristics of the proposed modification. The AFLC Form 48 is the major instrument which the CCBs use to evaluate the proposed benefits of a modification (2:26).

STATEMENT OF PROBLEM

As Halsam and Berger found in their study (13:1), each year the Air Force spends several hundred million

dollars updating its aircraft fleet. The study also showed that an intricate management structure has been developed to review, approve, coordinate, and implement the total modification program.

One of the major concerns regarding the Air Force modification program has been the increasing proportion of the total budget which is used for modification of aircraft. For example, a study by Bryant (4:30-35) showed that for each of the years from 1960 through 1970 the budget for modification of aircraft was more than 25 per cent of the budget for procurement of new aircraft.

There is still a high investment in aircraft modifications. During the period 1972-1976, the Air Force invested over $500 million in modifications which were designed to improve the reliability and maintainability of aircraft. Although significant investments have been made in modifications to improve weapon system performance and supportability, no formal system exists to evaluate whether actual benefits do materialize (33).

The Air Force needs to know if improvements in logistic support are actually achieved from Class IV modifications. Toward fulfillment of this need, an apparent requirement exists for development of a technique for determining if aircraft reliability, maintainability, and availability are significantly increased after incorporation of Class IV modifications on aircraft equipment.

JUSTIFICATION FOR STUDY

In the April 1976 issue of the Defense Management Journal (10:1), it was highlighted that the Air Force has, in the last few years, emphasized that its weapon systems are modified to increase availability while keeping logistics support costs down. This concern for improving availability and decreasing support costs is a result of continuing reductions in the defense budget both in absolute dollar terms and as a percentage of gross national product. These same fiscal constraints limit the number of new weapon systems entering the active inventory as well as the number of individual units of a system that are produced. Paradoxically, encountering the enemy threat requires more complex and more expensive weapon systems.

Operational And Support Costs

The Operational and Support (O&S) cost of Air Force aircraft has become one of the most urgent problems facing the Department of Defense today (9:24). During the past ten years, O&S costs have been increasing while appropriated funds have shrunk in terms of real purchasing power. The net result is fewer dollars with which to develop and procure technologically superior weapon systems and modify the current aircraft inventory (9:24).

In the past, Air Force weapon systems have been procured with various problems of low reliability and high

O&S costs. For example, the F-111 aircraft was acquired with specified equipment that was just barely within the state-of-the-art. Because of deficiencies in equipment, repeated and costly modifications had to be completed on the aircraft after it was introduced in the field (12:29). The problem of low system reliability and maintainability resulted in decreased performance capability, increased maintenance manhour expenditures, increased failures and aborts, more expensive spare parts procurements, and costly product improvement modifications.

Benefits Identification

As indicated by a study conducted at the Defense System Management School in 1974 (4:35), the Air Force did not at that time have a systematic verification procedure for determining the benefits derived or results achieved from its aircraft modification program. The study stated that for modification expenditures in excess of $5 million, a verification program was needed to determine if the proposed improvements in equipment performance and reduction in O&S costs were being achieved.

A GAO study in October 1977 (32) also emphasized the need for DOD to develop a system or criteria for determining the results obtained from its aircraft modification programs. The GAO study investigated whether the current DOD emphasis on improving reliability and maintainability in its weapon systems has reduced operating and support

costs. The study sought to determine how cost savings attributable to improved equipment reliability and maintainability could be measured. The study concluded that current data systems and reasonable criteria do not exist for measuring, evaluating, or tracking the effects of reliability/maintainability improvement efforts on weapon system performance and O&S costs.

The purpose for developing a verification system would be to confirm whether improvements do occur from the aircraft Class IV modification programs. Confirmation of achieved benefits would hopefully enable the Air Force to obtain increased funding for its modification program, whether it be from existing Air Force sources or through increased Congressional support for future funding for aircraft modifications (18).

As a part of the verification system, the development of an analytical technique would be extremely helpful to Air Force managers for verification of the benefits that are obtained from specific Class IV modifications. This type of analysis would hopefully provide information for justifying similar modifications in the future and assist in deciding which particular categories or types of modifications provide the greatest improvements and benefits. The technique would also provide a check of the information included on the AFLC Form 48. In addition, it would provide information which could be used as feedback

to the Configuration Control Boards (CCB) on the effectiveness of approved modifications. This feedback would enable the CCB to determine whether the AFLC Forms 48 were accurately reflecting the impact and benefits of the future modifications accomplished. Hence, the availability of such a technique would, hopefully, allow for improvements in the entire Air Force Class IV modification process.

CURRENT EFFORTS

The preceding discussions may have led the reader to believe that there are no systems in being or under development to track and/or analyze the effect of modifications designed to improve logistics support. This was not the intent. Although no tracking system has been designed and documented for Air Force-wide application, there are ongoing efforts to develop such a capability. Some of the Air Force's current efforts in developing a modification tracking technique are described briefly in the sections which follow.

<u>K051 Modification Tracking System</u>

The K051 Modification Tracking System is a subsystem of the AFLC Improved Reliability of Operational Systems (IROS) program. The scope of the AFLC IROS program includes the following:

> The composite effort of all functional elements (that is, maintenance, procurement, operations, engineering, supply, materiel management, quality control, and transportation) to obtain, retain, and improve the performance and reliability of systems/subsystems/components/parts on a logistics effectiveness basis . . . [30:10-1].

Within the AFLC IROS program various data (such as maintenance data, status data, and safety data) are processed through program models to produce numerous displays or output formats. One such set of displays is the K051.BTXL products which are formally entitled "Audit of Class IV Modifications by Mod Number" and referred to herein as the K051 Class IV Modification Tracking System. This system has not been fully documented and was not briefed at the October 1977 Product Improvement Program meeting because "it contains the inherent assumption that a modification affects only one piece of hardware (WUC) in one weapon system" (29:5). This is because failure, maintenance, and status information are aggregated by work unit code (WUC) in the maintenance data collection system from which the IROS program draws its data (30:10-1). This deficiency would be present in any tracking or analysis system which depended upon the maintenance data collection system for its input data. Another apparent deficiency of this system is that it only allows one to determine the overall contribution of the WUC to logistics support cost or availability degradation. It does not permit separation of the variables which may be causing system availability

degradation. For example, an item (WUC) may be modified because of a high contribution to system Not Mission Capable Maintenance (NMCM) time. If, after modification, there was an increased contribution by this WUC to system availability degradation because of nonavailability of spares, any improvements made would be masked.

Air Force Academy Effort

Mitchell and Carter conducted a research effort and reported their results in February 1978 in which the objective was to investigate the modification history on the F-4 aircraft and to ". . . model reliability improvement at the aircraft level [20:iii]". The draft report of this effort indicated that insufficient data were available to meet the research objective. However, the data were sufficient for doing some developmental work on a modification tracking and analysis system.

Essentially, the procedure developed by Mitchell and Carter used a "matched pairs" statistical test to test for differences in the means of selected variables (maintenance actions, maintenance manhours, and failures) applied to a specified WUC before and after modification (20:9-14). This approach was appealing because it allowed individual assessment of variables which were indicative of system reliability and maintainability. Some of Mitchell and Carter's procedures for adapting the G098 data system to track aircraft performance variables have been used in this study.

PRAM Program

In July 1975, the Air Force established the Productivity, Reliability, Availability, and Maintainability (PRAM) program. The primary objective of this program was to focus management attention and funds in a concerted effort to reduce operational weapon systems support costs by innovative investment in cost-reducing opportunities. One anticipated benefit would be improved weapon system reliability, maintainability, and supportability (9:24).

Currently, the PRAM office maintains a data source of information called LIST (Logistics Investment Screening Technique) (11). The basic strategy and intent of the data source are to provide a listing by work unit code of aircraft equipment items that possess a high benefit-to-investment ratio for reliability improvement. The purpose for establishing the data was to allow equipment and weapon system managers to isolate equipment items with the greatest opportunities for benefits for modification dollar invested. Furthermore, it should help identify those items that may improve weapon system availability, reduce aborts, and reduce logistics support costs (11:8). Because this technique has just recently been developed, its impact on the modification process can not be evaluated.

CURRENT PROBLEMS

In an October 1977 article in the Defense Management Journal, Kern of Hughes Aircraft discussed the problems that the Air Force experiences when comparing equipment reliability which is based on actual field operation with the equipment reliability obtained from laboratory tests. The article emphasized that the disparity between the values can be attributed to differences in definitions of terms, operational factors, and environmental factors (14:18).

The problems that Kern discussed are generated by the inconsistencies in the criteria used for assessing field data generated by various aircraft systems. These inconsistencies result, primarily, from differences in definitions used for such things as time and failure (14:18). Air Force Logistics Command (AFLC) relies primarily on weapon system flying hours, rather than equipment operating hours, as the time base in calculating mean time between failures.

The Maintenance Requirements Data System (G098) which will be used in this study as the source of historical data on aircraft performance does not maintain equipment operating time and the information is difficult to obtain since total operating time is only maintained on a few selected equipment items. For these reasons, equipment operating time accrued during ground operation or during

operational checkouts and maintenance is not analyzed in this study. It will be assumed that flying hours and sorties will provide relative measures of total equipment operating time.

The failure data in G098 also includes some information that would not be considered as relevant for reliability test assessment purposes (29). For example, as Kern explained in his article, an item may be removed for external causes such as improper troubleshooting or faulty test equipment. This will result in mistakenly replacing the equipment which really has not failed. In addition, the equipment item may be removed and replaced for other externally caused factors such as broken, bent, loose, cracked, or missing components that do not affect the operational status of the item. These replacement actions would not normally be included in the assessment of the inherent equipment reliability but these actions will be included in the failure data maintained in the G098 system. These types of failures will also result in maintenance actions and maintenance manhours being documented against a system.

SCOPE

This research is limited to aircraft modifications which fail in the correction of material deficiencies (Class IV) category. As described previously, the

objectives of Class IV modifications can be summarized as: (1) improved maintainability, (2) improved service life, (3) improved logistics support--implying improved reliability, and (4) reduced costs.

Class I and II modifications were not considered in this research because they pertain to a small number of aircraft for a short period of time and generally do not address reliability. Class III modifications were not considered because they pertain only to aircraft in production. Class V modifications were not considered because they provide new capabilities.

Within the Class IV category, the data of concern in this study were limited to those that provide indications of changes in equipment reliability, maintainability, and availability.

RESEARCH QUESTION

Can a systematic technique which uses available systems data be developed to determine whether or not the stated purposes appearing on the AFLC Forms 48 as part of the original justification for Class IV modifications have been achieved?

RESEARCH OBJECTIVES

The primary objective of this research was to develop a technique for assessing the effectiveness of

logistics support (Class IV) modifications. A secondary objective was to use the developed technique to assess the effectiveness of selected Class IV modifications.

SUMMARY

This chapter has provided the background and justification for this study. It has briefly explained the problem and some current Air Force efforts in resolving it. Some aspects of the current aircraft modification process were explained. Finally, the scope, objectives, and research question were provided.

Chapter 2 will discuss the data collection process and the variables utilized in this research. Chapter 3 will describe the technique and the steps that were used in analyzing modification data. Chapter 4 will present the application of the technique to selected modifications and Chapter 5 will include the summary, conclusions, and recommendations for future research.

Chapter 2

OVERVIEW OF DATA AND VARIABLES

This chapter outlines the procedures employed by the authors to collect the data used in this research effort, describes the sources of data, and provides the criteria used to select the modifications used in this study. Additionally, it defines the variables of interest in this study, and identifies some variables which may affect logistics support but which were excluded from the analysis.

DATA COLLECTION

Initial development of the technique described in this study was done on data used by Mitchell and Carter in their study (20). These data did not provide any indication of the effects of a modification on availability. It was therefore determined that other modifications used should include Not Operationally Ready Maintenance (NORM) and Not Operationally Ready Supply (NORS) time as measures of availability.

The authors had initially assumed that complete records of past modifications were maintained at Headquarters AFLC. Interviews with personnel of the AFLC

Materiel Support Division (AFLC/LOAT) disclosed that Headquarters AFLC only maintained records for active modifications approved at that level. It was therefore concluded that an Air Logistics Center (ALC) would be a more appropriate source for identification of modifications to be studied.

In light of the above, a visit was made to the Policy and Programs Section (MMMMP) at Warner-Robins ALC. From a review of a card file maintained by this office, 58 modifications were selected as potential candidates for further study. The criteria used in this initial selection were as follows:

1. The modification had been completed for a minimum of six months. This criteria insured that 18 months of operational time had been gained on a representative number of modified aircraft. Eighteen months of operational data were required to minimize the effects of factors not analyzed in this research.

2. The modification was a Class IVA, IVB or IVC. Initially, this criteria required Class IVC modifications only. However, due to the paucity of data on the Class IVC modifications, the criteria were relaxed to allow for the inclusion of Class IVA or Class IVB modifications which had improvement of one of the logistics support elements as a strong secondary objective.

The Configuration Control Board Item Records (AFLC Forms 48) for the 58 modifications initially identified were then reviewed. The criteria used to select modifications for further review and/or analysis were:

1. A stated purpose of the modification was to reduce manhours, maintenance actions, NORM or NORS hours, failures, or to improve reliability.

2. The AFLC Form 48 contained a data code (for aircraft controlled by the Advanced Configuration Control System). This was required to extract the date individual aircraft were modified from the historical records.

3. The AFLC Form 48 contained a work unit code which was required to extract performance data from the G098 data system (explained in greater detail later in this paper).

Only 15 modifications survived this second screening. Five of these were modifications of equipment/systems on the HH-53 helicopter for which no data were available in the G098. The predominant reason for elimination of the initial 43 modifications was the absence of a work unit code on the AFLC Form 48.

The modification selection method required the personal involvement of one of the authors and time constraints prevented multiple ALC visits. Therefore only C-130, C-141A, F-4C/D/E, and F-106 aircraft are represented in this study.

Historical tapes, containing the serial numbers of aircraft receiving the modifications and the dates the modifications were accomplished, were provided to the Scientific and Engineering Systems Unit (ACDCK) at San Antonio ALC by personnel from the Requirements Section (ACDCH) at Warner-Robins ALC. These data were then merged with data contained in the Maintenance Requirements Data System by personnel from San Antonio ALC (ACDCK) who used a program which they maintain. The data were then provided to the authors on punch cards.

DATA COLLECTION STEPS

The steps in the data collection process are shown in Figure 2-1. Numbers in the figure are coded to the steps described below.

Step 1. Determine Data Requirements

The authors were interested in determining which, if any, of the previously described logistics support elements were improved by the selected modifications for the purpose of developing an evaluation technique. Therefore, all data considered to be relevant to this determination were required. The order of this step and the next could logically be reversed if one were only attempting to evaluate the effectiveness of a specific modification.

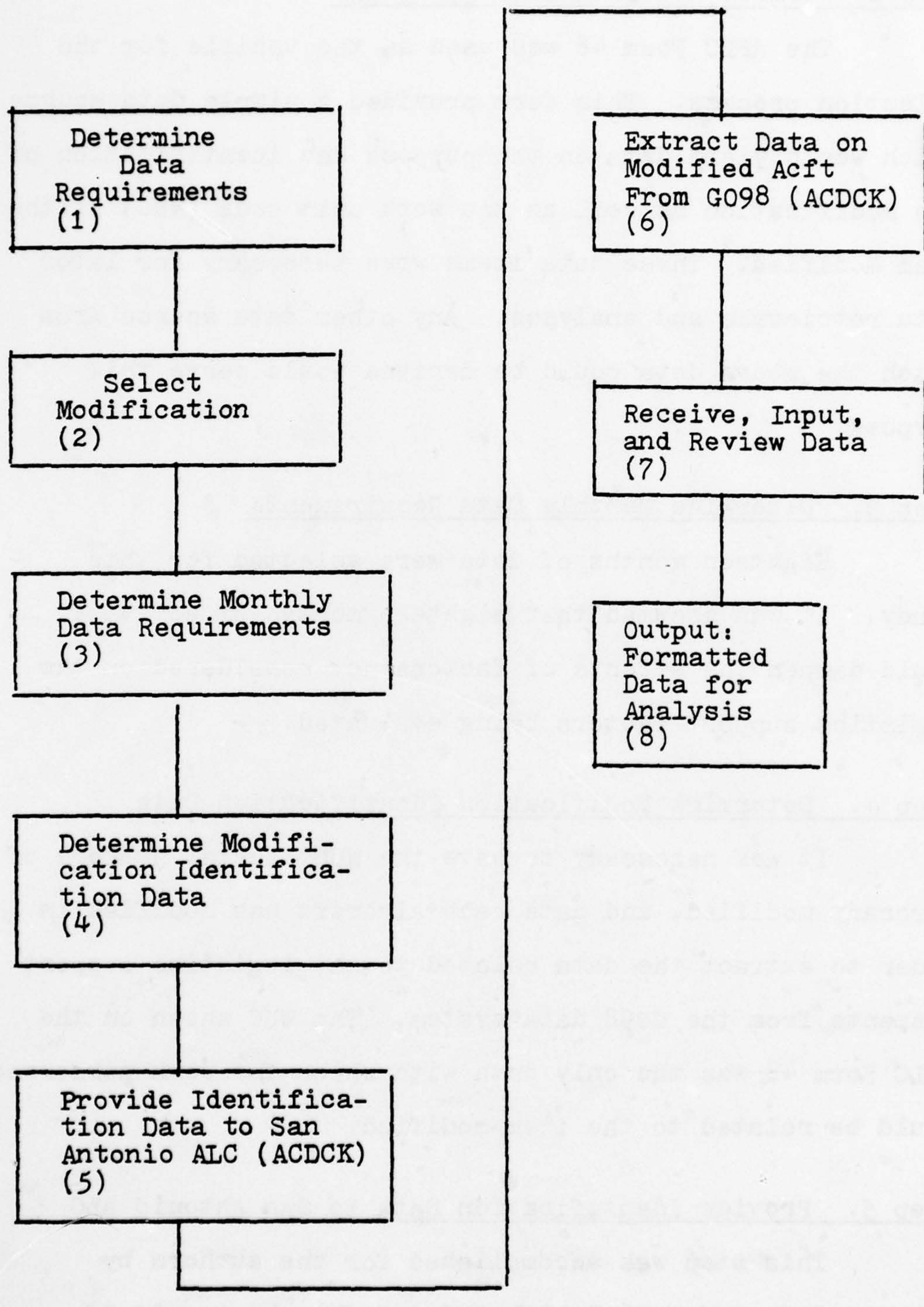

Fig. 2-1. Data-Gathering Process

Step 2. Select Modifications For Study

The AFLC Form 48 was used as the vehicle for the selection process. This form provided a simple data source which would yield data on the purpose and identification of the modification as well as the work unit code (WUC) of the item modified. These data items were necessary for later data retrievals and analyses. Any other data source from which the above data could be derived would serve this purpose.

Step 3. Determine Monthly Data Requirements

Eighteen months of data were selected for this study. It was assumed that eighteen months of activity would dampen the effects of factors not considered on the logistics support factors being evaluated.

Step 4. Determine Modification Identification Data

It was necessary to have the WUC, serial numbers of aircraft modified, and date each aircraft was modified in order to extract the data related to the logistics support elements from the G098 data system. The WUC shown on the AFLC Form 48 was the only data with which the work performed could be related to the item modified.

Step 5. Provide Identification Data To San Antonio ALC

This step was accomplished for the authors by personnel from Warner-Robins ALC (ACDCH) who provided

San Antonio ALC (ACDCH) with copies of the D047 (C-130 modifications) and D057G (C-141 modifications) historical tapes. The data code for the modification allowed the San Antonio ALC personnel to select the aircraft serial numbers and dates of modification from the historical tapes. The WUC and number of months of data required, allowed extraction of failure, maintenance actions, manhour consumption, and contribution to nonavailability data (as related to the identified WUC) from the G098 data system.

Step 6. Extract Data From The G098 Data System

This step was accomplished by San Antonio ALC (ACDCK) personnel with a program developed and maintained by them. Essentially, the program allows compilation of logistics performance data for a specified period of time before and after a modification.

Step 7. Receive, Input, And Review Data

The data were received from San Antonio ALC (ACDCK) in punched card form as a matter of convenience to the authors. Tape output could have just as easily been provided. The data were then reviewed to ensure that the format was amenable to analyses and served as input to programs developed locally.

Step 8. Formatted Data For Analysis

This was the output step of the data gathering process. The data were now ready to be used as the input to the analysis process.

AVAILABLE DATA SOURCES

A review of current Air Force literature (30, 31) revealed that there are numerous sources of data on historical performance of aircraft in the Air Force inventory. However, the most extensive source of data on system/equipment operational performance is provided in the Air Force by two primary data reporting systems. One of these is the maintenance data collection system specified in the 00-20 Series Technical Orders and Air Force Manual (AFM) 66-1. The other is the standard aerospace and equipment status reports specified in AFM 65-110.

The Maintenance Data Collection System (MDCS) is primarily directed toward the recording and reporting of base maintenance activity but it is also required for contractor and depot level maintenance. Basically, the MDCS provides the following data:

1. Work done.
2. Why the maintenance was necessary.
3. When the discrepancy was discovered.
4. Who did the work.
5. How many manhours did it take.

The above information is recorded by the technician when he accomplishes a job. The technician specifies the

equipment item that the work was accomplished on by use of a 5-digit Work Unit Code (WUC). AFM 65-110 data provide information on equipment inventory, operating time, and availability (operational status) and are also provided from base level managers.

These two data systems have been merged into the G098 data system which is maintained by Kelly AFB. In this study the G098 system was selected because it was determined that it is the most complete data storage and retrieval system available in the Air Force. The G098 system is maintained, however, only on selected aircraft. It is important, then, to insure that in the data collection process that aircraft selected for analysis were currently maintained in the G098 system.

PROBLEMS WITH DATA

The AFM 66-1 information system has been criticized for its inaccuracy. In a recent study by Badalamente and Clark, it was stated:

> Perhaps the most often cited shortcoming of the MDC system is the inaccuracies in its data and the resultant unreliability of its output. The criticism was first formalized in a 1965 IG Report, which stated that there was 25 to 400 percent padding in manhour data and a 40 percent error rate in MDC product improvement data. . . . Numerous attempts have been made over the years to improve MDC accuracy and there has been continuous and sometimes brutal high-level emphasis on accurate documentation at base level. Nevertheless, the perceived if not actual, accuracy and reliability of the MDC system remains low [1:12].

In the conclusion of their study the authors provided some suggestions on how to improve the MDC system. Basically, they concluded that the MDC system in its current form has the potential to support decision making at various levels of the logistics management function (1:22-23).

Other studies have been completed that also commented on the accuracy of the 66-1 MDC system. A RAND study in 1975 (8) that evaluated the Air Force IROS system as an accurate estimator of logistics support costs commented on the accuracy of MDC data used in IROS:

> In almost any cost analysis, comparative or otherwise, there are limitations imposed by the lack of adequate data, and this study is no exception. The basic data systems that we relied on for our reference costs are not perfect. These data products contain ambiguities and in some instances are possibly incomplete. However, they do reflect direct recordings of the maintenance and material resources consumed to support the weapon system of interest [8:4].

The RAND study commented on some of the specific deficiencies in the MDC system. The study indicated that the MDC data system does not consistently record all relevant maintenance actions. The study referenced another RAND report (25) that found in 1973 that base-level repair actions were frequently lost or not indicated in the MDC system. The report stated:

> For example, within a job control number a common sequence of actions is a pull, a repair, and a replace. When one component of this sequence is missing in the MDC 66-1 report (e.g., if only a remove and replace were recorded), there is a logical error of omission. These data deficiencies in MDC

> 66-1 are seemingly passed on to the K051 [IROS] reports, since there is no apparent input data logical sequence quality check. On the other hand, the MDC system is a self-recording system and one has also to check for exaggerated numbers of maintenance hours reported--numbers incompatible with the resources available for maintenance [8:17].

A 1978 study authored by Stanhagen (24) described an investigation into the accuracy of MDC data used in the Air Force. The report emphasized that in addressing the accuracy of the data there are two basic methods for errors to develop. The first being an error in the technical competence of the mechanic who supposedly corrects the discrepancy. The mechanic may not complete the proper troubleshooting and therefore repairs the wrong item. This would result in a documentation error where the wrong WUC is credited with causing the discrepancies and having erroneous maintenance data coded against it. This type of error can occur in any type of collection system and can be reduced by properly training and supervising the mechanics. The other type of error results from the mechanic who repairs the correct item but copies down the wrong WUC, action taken code, how malfunctioned code, and so forth.

In this study, 168 Air Force aircraft mechanics were identified as participants in a test program. The mechanics were given specific tasks to complete on C-135 aircraft. The work they accomplished was then evaluated by a panel of six "experts" to determine how accurately the mechanics coded their work. The final conclusion from this

study was that MDC "data is indeed accurate and capable of providing an effective basis for logistics decision making [24:57]."

A briefing at the October 1977 Product Improvement Program (PIP) Problem Definition meeting at Wright-Patterson AFB also addressed the validity of data collected by AFM 66-1. The position of the representatives from Warner-Robins ALC was that they realized that the data may be inaccurate to some extent. However, they indicated that "there appears to be no alternate source of data which can provide comparable information [29:87]." The briefing continued:

> When component or system problems arise, 66-1 data including the "on equipment" information, provides valuable insight into the problems resolution and often provides a substantial justification for any follow-on modification proposal. WR-ALC position [is to] retain the collection of on equipment data [29:87].

DATA SOURCES UTILIZED

The data used to measure the variables in this project were initially extracted from the Advanced Configuration Management System (D057G), The Standard Configuration Management System (D047), and the Maintenance Requirements Data System (G098) by personnel assigned to the data automation center at Kelly AFB. The D057G and the D047 contain modification data and allows one to determine the date a specific aircraft was modified (20:6). The G098 data system was designed in 1970 to provide a data base containing

historical data which could serve as the basis for the engineering determination of content of and interval between programmed depot maintenance. The file contains aircraft maintenance, inventory, utilization, and status information for each aircraft by tail number since 1966 (29). The data from the D057G and G098 were then merged at Kelly AFB to provide the information to analyze the effectiveness of a specific modification.

A list was compiled of aircraft by tail number that had been modified. Data were provided from the G098 data system for a specified period of time before and after the modification on the following variables for each tail number: (1) flying hours, (2) sorties, (3) maintenance actions, (4) maintenance manhours, (5) failures, (6) Not Operationally Ready Maintenance (NORM)*, and (7) Not Operationally Ready Supply (NORS)*.

The last variables (maintenance actions, manhours, failures, NORM, and NORS) contain data on the modified part identified by a specific Work Unit Code (WUC). It should be emphasized that only maintenance data related to this specific WUC are of interest for the analyses accomplished in this study. The data compiled in G098 are obtained from

*These two variables were changed to Not Mission Capable Maintenance and Not Mission Capable Supply on 1 October 1977. The old nomenclature is used in the analyses to maintain consistency with the terminology in use at the time of modification development and approval.

work reports documented in the field by maintenance technicians. Each job accomplished in the field must identify the WUC or equipment item that the job related to. This identification system allows specific tracking of how much logistic support was required to maintain a specific equipment item.

POPULATION

The population for which the technique was developed includes all modifications designed to improve logistics support.

SAMPLE

The sample against which the technique was applied consisted of three Class IVC, one Class IVA, and four Class IVB modifications selected by the authors in accordance with the data gathering plan presented earlier. One F-106 Class IVB modification was selected by San Antonio ALC (ACDCK) personnel to test the data retrieval program and was subsequently used in the analysis process. In addition, the data on five modifications (four Class IVA and one Class IVB) used by Mitchell and Carter in their research (20) were also analyzed.

VARIABLES

In discussing product improvements in the Air Force logistic managers should become concerned about analyzing such parameters as reliability and maintainability which are determinants of logistic support requirements. These parameters have considerable importance when designing a new weapon system. In the life cycle cost approach to Air Force weapon system acquisition, considerable emphasis should be placed on these parameters in an attempt to reduce operational and support costs.

In 1976, the Department of Defense began to establish reliability goals and thresholds for new weapon systems in the Decision Coordinating Paper (DCP). Actual equipment reliability values will be calculated using field data collection ground rules and procedures (19:6). Therefore, it has become important that logistic support parameters be understood in terms of variables maintained on Air Force weapon systems in current maintenance data information systems.

Variables Used

The variables, their definitions, and their data level analyzed in this study are as follows:

Failure. A ratio level, discrete, infinite variable which is reported for those maintenance actions on the equipment under consideration charged with a failure

malfunction, a repair or replacement action, and which were discovered by the aircrew.

Maintenance manhours. A ratio level, discrete, infinite variable which is reported by the mechanic at the time of his maintenance action. These data indicate the number of manhours extended by the mechanic to correct a specific reported failure.

Maintenance action. A ratio level, discrete, infinite variable which is considered as any action taken on the equipment under consideration for which the mechanic charges some expenditure of time.

Flying hours. A ratio level, discrete, infinite variable which is the time, in hours, between aircraft takeoff and an associated landing. For any period of time, the flying hours are given as the sum of the flying hours from all sorties for that period.

Sortie. A ratio level, discrete, infinite variable which is reported as an event consisting of one takeoff and associated landing.

NORM. A ratio level, discrete, infinite variable which is the time, in hours, that a weapon system is unavailable for its assigned mission due to a particular maintenance action being accomplished on equipment.

NORS. A ratio level, discrete, infinite variable which is the time, in hours, that a weapon system is

unavailable for its assigned mission due to lack of a required part.

Using the above variables currently maintained in maintenance data systems the following relationships were assumed and used in this study to help describe some of the parameters that affect weapon system performance and logistic support:

1. Failures and maintenance actions provided an indication of equipment reliability.

2. Maintenance manhours provide an indication of equipment maintainability.

3. Flying hours and sorties provide an indication of weapon system activity.

4. NORM and NORS hours provide an indication of system availability degradation attributable to the modified equipment.

Additional Factors

In the current literature, there is considerable concern about what effects different factors have on weapon system performance (7, 14). Kern described some of these in his article under the general headings of operational and environmental factors. The following factors have been discussed in the current literature (7,14,19,31) as possible factors affecting not only logistic support but system performance in general:

1. Material Handling: The amount a given item is subjected to transportation and maintenance handling in terms of removal rate from the aircraft for repair or bench checks.

2. Base Maintenance Policy: Local base policies concerning cannibalization, operational checks, shop repair policy, training and skill levels of mechanics, and other base unique maintenance policies.

3. Environmental Influences: Climatic and temperature variations, humidity, dust, and other conditions unique to a particular base.

4. Mission: Unique mission of the base may require greater utilization of a particular system or component. Unique missions cause different stresses to be placed on particular systems.

5. Facilities: Hangar facilities, shop test equipment, condition of ramps and taxiways, outside lighting, and other facilities determine type and quality of maintenance that can be accomplished on a system.

In this study, it became apparent that these factors were not quantifiable from the available data and were excluded from the analysis. For example, a system could be inoperative and go undetected because no demand was placed on it for the particular mission being flown. This obviously would affect the number of failures, maintenance manhours, and maintenance actions documented against the system.

SUMMARY

This chapter has described the data collection process that was used in this study. The criteria used in selecting the modifications analyzed in this research were also explained. Available data sources and their inherent problem areas were discussed. Finally, the variables used in the analyses were defined along with the factors not considered in this study. The discussions in Chapter 3 will address the technique development.

Chapter 3

TECHNIQUE DEVELOPMENT

The purpose of this chapter is to provide a detailed description of the analytical technique employed in this research effort, the statistical tests utilized, and the rationale for the use of the technique.

APPROACH

The general premise of this research effort is that the mean values (before and after a modification) of the variables under consideration can be compared to provide an indication of the effects of the modification. If there is no significant difference between aircraft activity before and after the modification, the comparisons can be made directly. However, if there is a significant difference in aircraft activity during the two periods, the variable value must be normalized (divided by an appropriate activity measure) before the comparison is made.

Aircraft and engine performance is commonly measured in flying hours. These same flying hours are also generally applied to the aircraft equipment as a measure of operating time. Many studies have been made of flying hour/sortie relationships. These studies indicate that

in some cases sorties provide a more definitive performance measurement (31:18).

For these reasons, the data describing the variables in this research effort were compared directly and were also compared after being normalized by flying hours and sorties. The steps in the process are displayed in Figure 3-1. The normalization process was included in the computer programs used to perform the statistical analyses (described later in this chapter).

The following steps as shown in Figure 3-1 were used in the analysis of data.

Step 1. Establish Criteria

The criteria that were used in this study to determine the effectiveness of the modification being analyzed were developed in this step. A modification was determined to be effective if it achieved the purpose as indicated in the modification's approval justification on the AFLC Form 48 and no other variables increased after the modification.

Step 2. Perform Statistical Analyses Of Data

The following paragraphs describe the statistical analyses that were utilized in this technique. Utilization of these particular statistical techniques are described in greater detail later in this study. The selection of the statistical hypotheses, test statistics, and decision rules will be determined by the researcher and will depend on the

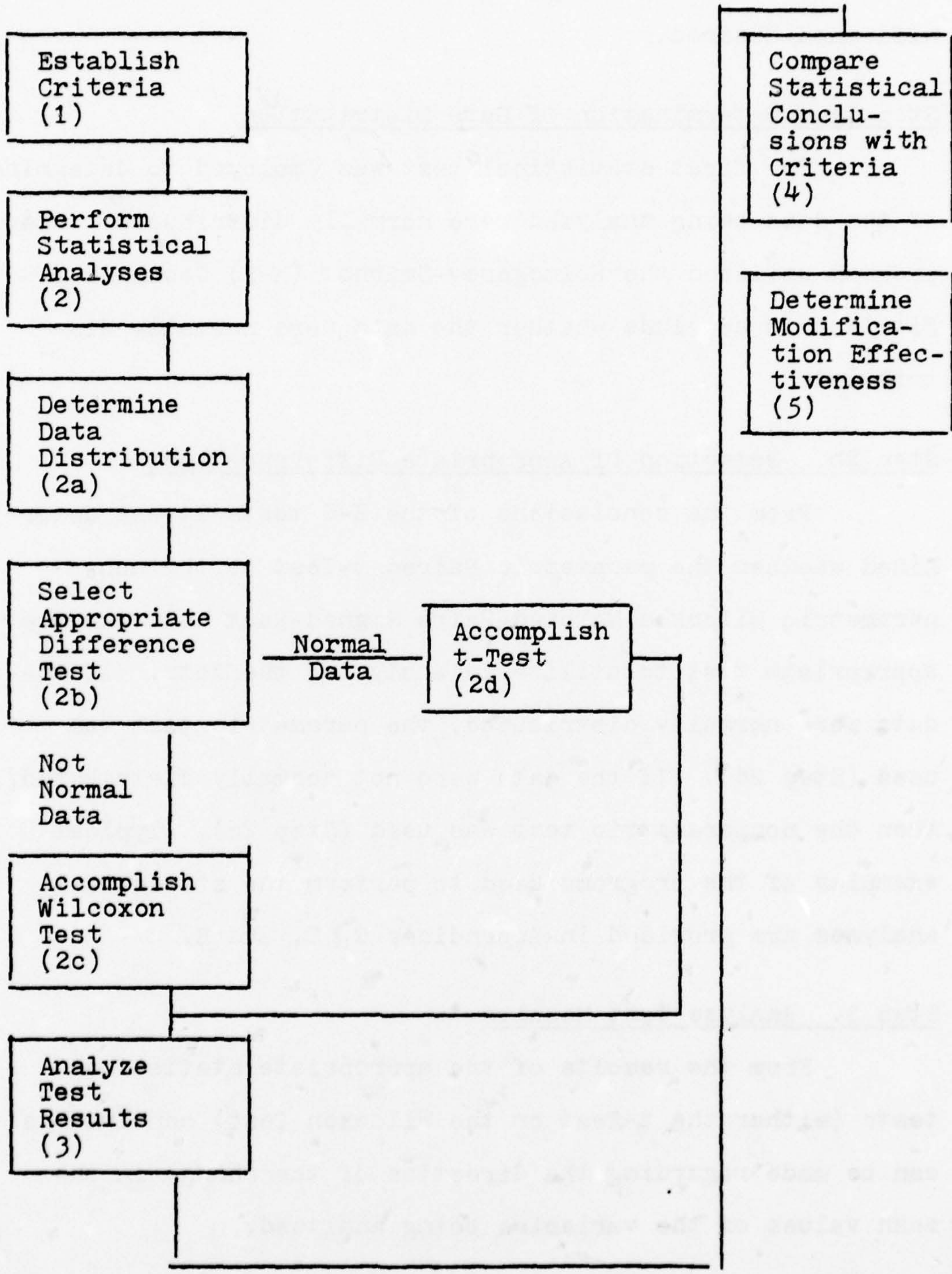

Fig. 3-1. Data Analysis Approach

particular variables being analyzed and the level of significance desired.

Step 2a. Determination Of Data Distribution

The first statistical test was employed to determine if the data being analyzed were normally distributed. The program utilized the Kolmogorov-Smirnov (K-S) Goodness-of-Fit Test to conclude whether the data were normally distributed.

Step 2b. Selection Of Appropriate Difference Test

From the conclusions of the K-S tests it was determined whether the parametric Paired t-Test or the nonparametric Wilcoxon Matched-Pairs Signed-Rank Test was the appropriate test to utilize in analyzing the data. If the data were normally distributed, the parametric test was used (Step 2d). If the data were not normally distributed, then the nonparametric test was used (Step 2c). Typical examples of the programs used to perform the statistical analyses are provided in Appendices C, D, and E.

Step 3. Analyze Test Results

From the results of the appropriate statistical tests (either the t-Test or the Wilcoxon Test) conclusions can be made regarding the direction of the change in the mean values of the variables being analyzed.

Step 4. Compare Statistical Conclusions With Criteria

The conclusions developed in the previous step regarding the modification's effects on the test variables were compared to the established criteria.

Step 5. Determine Effectiveness Of Modification

The results of the statistical analyses were compared with the established criteria. The results of this comparison determined the conclusions reached regarding the specific effects of the modification and determined whether the modification was effective.

STATISTICAL TESTS

Three statistical tests were utilized in this technique. The Kolmogorov-Smirnov Goodness-of-Fit Test was used to determine which of the variables being studied were normally distributed. If normality could be proven, then the Paired t-Test was used to determine if there was any statistically significant difference between the means before and after the modification under consideration. If the data were not normally distributed, the Wilcoxon Matched-Pairs Signed-Ranks Test was used to determine if any statistically significant difference existed between the means. The following discussion describes in detail the specific statistical tests.

Kolmogorov-Smirnov
Goodness-of-Fit Test

In this test, it was important to make some conclusions with some level of significance about the nature of the distribution of the population from which the sample data were drawn. In particular, it was important to know which of the variables under study were normally distributed. By knowing this, it was known what type of paired difference test to use on the data. If the variables were considered not to be normally distributed at some confidence level, then the Wilcoxon Matched-Pairs Signed-Rank Test was the appropriate nonparametric test (23:19).

The Kilmogorov-Smirnov Goodness-of-Fit Test was selected over the Chi-Square Goodness-of-Fit Test because the Chi-Square Test is not the most efficient test to fit sample data to an assumed population distribution. In the Chi-Square Test the random variables must be grouped into classes and the numeric value of each individual observation is lost (21:681).

Siegel discussed this test in the following manner:

> The Kilmogorov-Smirnov one-sample test treats individual observations separately and thus, unlike the Chi-square test for one sample, need not lose information through combining of categories. When samples are small, and therefore adjacent categories must be combined before Chi-square may properly be computed, the Chi-square test is definitely less powerful than the Kilmogorov-Smirnov test. Moreover, for very small samples the Chi-square test is not applicable at all, but the Kolmogorov-Smirnov test is. These facts suggest that the Kolmogorov-Smirnov test may in all cases be more powerful than its alternative, the Chi-square test [23:51].

The data in each case were assumed to be random, ratio level, and continuous. The test was run utilizing a program specified in the Northwestern University supplement to SPSS (26:12). Continuity was assumed even though maintenance actions and failures have discrete values.

The following discussion of this test is adapted from Siegel's text (23:47-51). The test involves specifying the cumulative frequency as being normally distributed. The cumulative frequency distribution is that distribution which is felt would occur under the theoretical distribution and is compared with the observed cumulative frequency distribution. The theoretical distribution represents what would be expected under the null hypothesis (H_0). Let F(X) be the specified cumulative distribution and S(X) the observed. Under the null hypothesis that the sample has been drawn from the specified theoretical distribution, it is expected that for every value of X, S(X) should be fairly close to F(X). Under H_0, then, we would expect the differences between S(X) and F(X) to be small with a 10 per cent chance of random error. The SPSS program computes the value at which the greatest divergence occurs. The absolute value of the largest value is called the maximum deviation, D, and is defined as:

$$D_{Max} = \text{Maximum} \left| F(X) - S(X) \right|$$

where:

$F(X)$ is the specified cumulative distribution and

$S(X)$ is the observed distribution.

In this test one must also apply the Lilliefors modification since the program calculates the parameters for the theoretical distribution from the sample (15). The following will be the general hypotheses for each variable, the test statistic, and the decision rule:

<u>General Statistical Hypotheses</u>:

H_0 : The random sample came from a normal distribution with mean ($\bar{X}$) and standard deviation (S) calculated from sample values.

H_A : The cumulative distribution function is not normal.

<u>Test Statistic</u>:

$$D_{Max} = \left| F(Z) - S(Z) \right|, \text{ where } Z = \frac{X_i - \bar{X}}{S}, \text{ and}$$

$i = 1, 2, \ldots n$

<u>Decision Rule</u>:

Reject H_0 if D_{Max} is greater than D_{Crit}.

$D_{Crit} = \dfrac{.805}{\sqrt{n}}$, where $1 - \alpha = .90$ and n is sample size (15).

This test was run on 34 data sets which are defined in Appendix A.

Paired t-Test

The Paired t-Test was utilized to determine differences in population means. The test assumes a dependence between the populations being compared. In this study, it was desired to compare the mean values for flying hours, sorties, maintenance actions, maintenance manhours, NORM, NORS, and failures before modification of a group of aircraft with the mean values of the same variables and same group of aircraft after the modifications.

The Paired t-Test is appropriate in many experiments in which the researcher is primarily interested in discovering and evaluating differences in effects rather than the effects themselves. In this study, the researchers were concerned with how a modification changes some variables related to aircraft reliability, maintainability, and availability rather than the specific values that relate to reliability, maintainability, or availability.

Another reason for desiring to use the Paired t-Test in this study was to eliminate the extraneous influences of material handling, environmental effects, maintenance policy, mission, and facilities on the variables that are being analyzed. In the Paired t-Test, only the paired difference variable $D = X_B - X_A$ is formed, where X_B is the measurement of the variable before the modification and X_A is the measurement after. For any pair of variables it was assumed that the extraneous factors were the same before as after

the modification. The difference, then, between the measurement before and after the modification was an estimate of the difference due to the modification. This type of statistical analysis leads to a more accurate comparison because the data are relatively more homogeneous (20:2).

To be able to utilize the Paired t-Test, the sample data have to be normally distributed. The results of the Kolmogorov-Smirnov Test was used to determine with a 90 per cent confidence level which of the paired sample data were normally distributed. The data were discrete and ratio level.

An SPSS program was used to accomplish the Paired t-Test on the sample modifications. The program computes the differences in the sample means of the test variables.* The SPSS program computes the mean difference by subtracting before data from after data. The following test statistics, statistical hypotheses, and decisions rules were used for this test:

<u>Statistical hypotheses for flying hours and sorties:</u>

H_0 : FLY A = FLY B

H_A : FLY A $\neq$ FLY B

H_0 : SOR A = SOR B

H_A : SOR A $\neq$ SOR B

---

*The variables represented by these and other abbreviations are included in Appendix A.

Two-tailed tests were accomplished since the desired result was to show that flying hours and sorties did not change in the data set. If this result was shown to be true at the 90 percent confidence level, then flying hours and sorties were shown not to have been a factor in any significant changes in the other five paired variable tests. If H_0 was not rejected, it was concluded at a 90 percent confidence level that aircraft activity was the same on either side of the modification. If this conclusion was not obtained, then the results of the remaining variable tests on maintenance actions, maintenance manhours, NORM, NORS, and failures were not conclusive as to what effect the modification had on the mean value of the variable tested.

Statistical hypotheses for other variables:

H_0 : MAB $\leq$ MAA

H_A : MAB > MAA

H_0 : MHB $\leq$ MHA

H_A : MHB > MHA

H_0 : NORM B $\leq$ NORM A

H_A : NORM B > NORM A

H_0 : NORS B $\leq$ NORS A

H_A : NORS B > NORS A

H_0 : FAIL B $\leq$ FAIL A

H_A : FAIL B > FAIL A

If the conclusion was made that flying hours and sorties were significantly different then the effects of this difference were eliminated by normalizing the variables. This was accomplished by dividing maintenance actions, maintenance manhours, NORM, NORS, and failures by their respective flying hours and sorties. The following are the statistical hypotheses for the resulting variables:

H_O : MABF $\leq$ MAAF	H_O : NORMBS $\leq$ NORMAS
H_A : MABF > MAAF	H_A : NORMBS > NORMAS
H_O : MABS $\leq$ MAAS	H_O : NORSBF $\leq$ NORSAF
H_A : MABS > MAAS	H_A : NORSBF > NORSAF
H_O : MHBF $\leq$ MHAF	H_O : NORSBS $\leq$ NORSAS
H_A : MHBF > MHAF	H_A : NORSBS > NORSAS
H_O : MHBS $\leq$ MHAS	H_O : FAILBF $\leq$ FAILAF
H_A : MHBS > MHAS	H_A : FAILBF > FAILAF
H_O : NORMBF $\leq$ NORMAF	H_O : FAILBS $\leq$ FAILAS
H_A : NORMBF > NORMAF	H_A : FAILBS > FAILAS

One-tailed tests were utilized since the analysts desired to conclude that the variables decreased after the modification with a 90 percent confidence level when compared to the test variables before the modification.

Test statistic:

$$t_S = \frac{\bar{d} - \mu_d}{s_d / \sqrt{n}}$$

where $\bar{d}$ is the average of the differences, μ_d is the difference between means (before minus after), s_d is the standard deviation of the differences, and n is the sample size, as defined in Pfaffenberger and Patterson (21:353). For each modification, this test statistic was computed by a SPSS program for each of the paired hypothesis tests.

Decision rules:

1. Reject H_0 if $|t_S|$ (absolute value) is greater than 1.64 (two-tailed test, $\alpha = .10$, $n - 1 > 30$). This decision rule was used for the hypotheses for flying hours and sorties.

2. Reject H_0 if t_S is greater than 1.28 (one-tailed test, $\alpha = .10$, $n - 1 > 30$). This decision rule was used for the hypotheses for the unnormalized and normalized maintenance action, maintenance manhours, NORM, NORS, and failure variables.

Wilcoxon Matched-Pairs Signed-Ranks Test

When the assumption of normality is not reasonable for the data being analyzed, nonparametric tests should be utilized to test hypotheses. The Wilcoxon Matched-Pairs Signed-Ranks Test is the nonparametric counterpart to the parametric Paired t-Test for testing differences between two means. This test was appropriate for those variables in the study that were shown not to fit the theoretical normal distribution in the Kolmogorov-Smirnov Test at an α value of .10.

These non-normal sample populations were tested with the Wilcoxon Test to evaluate what effects a modification had on the normalized and not normalized means of the maintenance action, manhour, NORM, NORS, and failure variables before the modification and after the modification. This Wilcoxon Test retains the convenience of the Paired t-Test in that it minimizes the effects of such factors, for example, as maintenance policy and geographical location on the data. The Wilcoxon Test is a more powerful test than the nonparametric sign test in that it not only provides information about the direction of difference within the paired data, but it also indicates the magnitude of the difference (23:75).

The Northwestern Supplement to SPSS described the Wilcoxon Test and provided the program that analyzed the data (26:21). The explanation of the results in this supplement are somewhat misleading, however, in that it did not provide a means for determining the variable that the test was computed for. Manual calculations were required to determine this information. This deficiency makes the program somewhat inconvenient.

The following discussion of the test is condensed from Siegel (23:75-83). The Wilcoxon Test first computes the difference (d) in the means between each set of matched pairs. Each pair has one (d). Each d is then ranked

without regard to sign. The rank of 1 is given to the smallest d, 2 to the next smallest, and so on until all the d's are ranked. If there is no difference in the pair, then these sets of data are discarded and ignored in the analysis. If there are different sets of data with the same d then such tied cases are assigned the same rank. The rank assigned is the average of the ranks which would have been assigned if the d's had differed slightly. As Siegel discussed, the practice of giving tied observations the average of the ranks they would otherwise have been assigned has a negligible effect on T_S which is the test statistic on which the Wilcoxon Test is based and which is defined below (23:77).

The next step in the Wilcoxon Test assigns the sign of the difference to each rank. This step indicates which ranks arose from negative d's and which ranks arose from positive d's. The sum of the negative ranks and the sum of the positive ranks are computed. The value of T_S is assigned to the smaller sum of like-signed ranks. The value of N (the number of matched pairs minus the number of pairs whose d = 0) is then computed.

Statistical Hypotheses:

The same statistical hypotheses were used in this test as in the Paired t-Test. The following test statistic and decision rule will apply to the hypotheses:

Test Statistic:

T_S = Smaller value of $n_A X$ (-Ranks Mean) and

$n_B X$ (+Ranks Mean)

where,

$$N = n_A + n_B$$

and where n_A is associated with after-modification data and n_B is associated with before-modification data. SPSS computes the difference in this study as,

Difference = After - Before

Decision rule:

Reject H_0 if $Z_S > Z_{Crit}$ for $\alpha = .10$

If $N > 25$, then the following test statistic and decision rule will be used to test the hypotheses:

$$Z_S = \frac{T_S - \mu_T}{\sigma_T}$$

where:

$$\mu_T = \frac{N(N + 1)}{4}$$

$$\sigma_T = \frac{N(N+1)\ (2N+1)}{24}$$

and T_S is as defined above (20:79).

If $N \leq 25$ then the Wilcoxon Test is not normally utilized and appropriate statistical tables are used. However, Siegel indicated that the test statistic and decision rules for $N > 25$ are excellent approximations for small samples, $N \leq 25$ (23:79). Therefore, in this study the

Wilcoxon Test was applied in those few cases when $N \leq 25$.

For two-tailed tests when H_0 is of the Form $X_B = X_A$:

1. If $Z_S > 1.64$ reject H_0 at 90 percent confidence.

2. If $Z_S < -1.64$ reject H_0 at 90 percent confidence.

For one-tailed tests when H_0 is of the form $X_B \leq X_A$:

1. If T_S is associated with negative differences, or in other words, if n_Ax (-mean ranks) < n_Bx (+ mean ranks) then if $Z_S > 1.28$ then reject H_0 at confidence level of 90 percent.

2. If T_S is associated with positive differences or, in other words, if n_Ax (-mean ranks) > n_Bx (+ mean ranks) then if $Z_S < -1.28$ (or Z_S is a more negative value) then reject H_0 at confidence level of 90 percent.

DESIGN TO MEET OBJECTIVES

The primary objective of this study was to develop a technique for evaluating the effectiveness of Class IV modifications in reducing logistics support requirements. A secondary objective was to evaluate selected completed Class IV modifications to determine if they were effective in reducing logistics support requirements. Some of the modifications evaluated had reduction of logistics support requirements as a secondary purpose. However, the evaluation of effectiveness related only to effectiveness in reducing support requirements. As a result, a modification, designed for safety or mission reasons, may have been

effective for its primary purpose but be judged ineffective in this study because it failed to achieve a secondary purpose.

Objective 1

There is no generally accepted method for determining the effectiveness of Class IV modifications against which this technique can be compared. The reader is encouraged to critically evaluate the proposed technique and to determine the efficacy of this approach for his purposes.

Objective 2

The following steps were followed to determine the effectiveness of the modifications evaluated during the course of this research:

1. A variable or variables was selected as representative of the logistics support element which the AFLC Form 48 indicated was to be improved.

2. The mean value of the selected variable before the modification was statistically compared with the mean value of the variable after the modification.

3. The modification was considered effective if the results of the statistical hypothesis test(s) allowed the strong conclusion that the mean value of the variable selected in Step 1 above was greater before the modification than after.

4. The modification was determined to be ineffective if:

a. the results of the statistical hypothesis test indicated that the mean value of the variable(s) representative of the purpose of the modification was not less after the modification than before or

b. the results of the statistical hypothesis test(s) indicated that the mean value of any other measured variable was greater after the modification than before.

ASSUMPTIONS

1. In the statistical tests utilized in this study, a confidence level of 90 percent was used. This confidence level was utilized since it is the confidence factor that is used in current military specifications dealing with reliability. As Thomas A. Budne explained in his article entitled, "Basic Philosophies in Reliability," a 90 percent confidence interval is utilized to insure that "there are fewer than ten percent of the production equipments which do not meet the reliability requirements [5:91]."

2. The previously described factors of material handling, environmental conditions, maintenance policy, mission, and facilities were assumed to have minimal effect on the variables analyzed. The assumption was made that the variables analyzed were affected by these factors to the same degree before the modification as after the

modification. Each aircraft served as its own control. This assumption made it easier to compare the differences between the measured variables. Any differences between the variables then was assumed to be a result of the particular modification.

3. It was assumed that the inconsistencies that exist in the data as a result of data collection and documentation errors were present to the same degree in the data compiled before the modifications as were present in the data compiled after the modification. By comparing differences in the variables it was felt that these data collection errors were greatly reduced or essentially eliminated.

4. It was assumed that a modification affected only that piece of equipment (WUC) identified on the AFLC Form 48. This study did not attempt to determine the effects of the modification on other equipment or systems on the aircraft.

5. It was assumed that all work accomplished on the modified equipment was documented by the technicians against the WUC that appeared on the AFLC Form 48. Attempts to regain data coded to higher or lower level WUC's were not made.

6. It was assumed that the effects of exchanging modified equipment between aircraft (by cannibalization or other maintenance actions) was not significant enough to affect the statistical analyses used in this study.

SUMMARY

This chapter discussed the specific technique that was developed to analyze the effectiveness of a modification. A flow chart was constructed to illustrate the steps used in the analyses of data. The specific statistical tests were explained in detail to emphasize the components of each test and the rationale utilized in developing the conclusions. Finally, the criteria used to measure the effectiveness of a modification and the assumptions made in this study were explained.

Chapter 4

ANALYSIS OF DATA

This chapter provides a detailed discussion of the analyses performed on fourteen modifications against which the technique developed in Chapter 3 was applied. Complete displays of the analysis results of Modification Number F65087B (Case 9) are provided. The results of the analyses for the remaining 13 modifications are summarized. Case 9 was selected for detailed presentation primarily because it appeared to be a "worst case" and provided a basis for discussion of all aspects of the analysis technique. Descriptive information for the modifications evaluated is provided in Table 4-1.

GENERAL COMMENTS

The following comments apply to all analyses performed.

Normality of Variables

The results of the Kolmogorov-Smirnov Goodness-of-Fit Test allowed the use of the parametric t-Test as the primary test for differences in only seven (7) of 208 possible instances. This occurred because in only these

Table 4-1

MODIFICATIONS EVALUATED

CASE NO.	MDC	MOD/TCTD NUMBER	MOD CLASS	WUC AFFECTED	TITLE OF MOD	PURPOSE OF MOD EVALUATED
1	F-4E	51158A	IVA	1226B	Replacement of Gas Powered Inertial Reel (Seat)	*Increase Reliability
2	F-4D	53025A	IVA	11230	Modification of aft locking lug wing fold rib, outer wing assemblies	*Reduce Failures
3	F-4C	51158A	IVA	1226B	Replacement of Gas Powered Inertial Reel (Seat)	*Increase Reliability
4	F-4D	51203B	IVB	1455G	Replacement of Center Leading Edge Flap Actuator Body	*Increase Reliability
5	F-4D	51158A	IVA	1226B	Replacement of Gas Powered Inertial Reel (Seat)	*Increase Reliability
6	F-106	1F-106-1121	IVB	63KB1	Replacement of UHF Antenna	*Reduce Manhours
7	C-130	F61618C	IVC	1129H	Modification of Paratroop Deflector Door	Reduce Failures, Reduce NORS
8	C-141	F61326C	IVC	14FAM	Modification of Auto-Pilot Inputs to Pitch Actuator	Reduce Failures, Reduce NORS
9	C-141	F65087B	IVB	11BAC	Cargo Ramp Overcenter Lock Condition	Reduce Manhours, Reduce NORM
10	C-141	F65104B	IVB	23HRA	Deactivation of fuel Inlet Low Pressure Warning Lights	*Reduce Failures and Manhours
11	C-130	60058C	IVC	22GCB	Installation of EHU-15 Turbine Inlet Temperature Indicators	Reduce Failures, Manhours, NORS and NORM
12	C-141	60014A	IVA	11FAA	Modification of Fuselage Station 351 Frame and Windshield Sill Channel	*Reduce Maint Actions and Failures
13	C-141	1C-141-1327	IVB	45C00	Installation of Accumulator in Nr. 3 Hydraulic System	*Reduce Failures
14	C-130	F61173B	IVB	13200	Installation of Restrictor in Nose Landing Gear Uplock line to Uplock Assembly	*Reduce Failures

*Secondary Purpose

seven instances was it found that both the before and after data were normally distributed. There were 12 other instances of normally distributed data. However, in these instances the data were distributed normally on only one side of the modification. It was therefore determined that the Wilcoxon Matched-Pairs Signed-Ranks Test would be the primary method used to test for decreases in the mean value of a variable after a modification. However, the t-Test was also applied. If the t-Test conclusions differed from those of the Wilcoxon Test, the Wilcoxon Test conclusions were the ones accepted unless this occurred on one of the seven instances when the t-Test applied directly. On the other hand, support of the Wilcoxon Test conclusions by the t-Test strengthened the Wilcoxon conclusion.

Normalized Variable Data

Statistical tests for equality of the activity indicators (flying hours and sorties) before and after a modification showed that in most cases (19 of 28 cases) activity was significantly different. It was therefore concluded that no useful information would be provided by inclusion of the analysis of nonnormalized variables. Sometimes analysis of normalized variables provided different conclusions according to whether the variable data was normalized by flying hours or by sorties. In these cases, it was necessary for the researchers to determine

(judgmentally), on a case-by-case basis, which of the two activity indicators (flying hours or sorties) was more appropriate.

Application of Criteria

The criteria for determining the effectiveness of a modification were as follows:

1. The mean value of the variable representative of the purpose of the modification indicated on the AFLC Form 48 was greater before the modification than after.

2. The mean values of other measured variables were not greater after the modification than before.

When the results of the statistical test on the appropriate hypotheses allowed the strong conclusion that the first criteria listed above had been satisfied, further analyses were required to determine if the second criteria was also satisfied. These analyses were accomplished by testing each variable whose mean value appeared to remain the same or increase after modification with a hypothesis test of the form:

H_0 : Variable Mean Value Before $\geq$ Variable Mean Value After

H_A : Variable Mean Value Before < Variable Mean Value After

If the null hypothesis (H_0) was not rejected, there was no statistically significant difference between the mean value of the variable before and after the modification.

Otherwise, the mean value of the variable was greater after the modification.

ANALYSIS OF CASE 9

Step 1. Criteria

This modification "Cargo Ramp Overcenter Lock Condition" was a Class IVB modification designed to prevent failure of the cargo ramp lock hooks and attendant cabin depressurization. The AFLC Form 48 description of the modification also stated that incorporation of the modification would "reduce extensive unprogrammed manhours/aircraft downtime required for a continuous ramp rigging inspection. . . ." The criteria selected for evaluation of the effectiveness therefore became:

1. The mean value of manhours expended against the work unit code modified (WUC 11BAC) must be less after the modification than before.

2. The mean value of NORM hours charged against WUC 11BAC after the modification must be less than those charged against WUC 11BAC before the modification.

3. The mean value of other measured variables, i.e., maintenance actions, NORS, and failures, must be no greater after the modification than before.

It was determined that sorties, rather than flying hours, would be the appropriate measure of cargo ramp activity because the cargo ramp is opened and closed

in-flight only on specialized missions. It was also felt that this system would be affected more by landings than by flying hours accumulated.

Step 2a. Determination of Data Distribution for Case 9

The Kolmogorov-Smirnov Goodness-of-Fit Test was performed at the 90 percent confidence level on the 34 variables associated with Case 9 to determine if the data were normally distributed. In only one instance (Sorties After) could the conclusion be reached that the data were normally distributed. In the other 33 instances, the strong conclusion was reached that the data were not normally distributed. The results of this test are summarized in Table 4-2.

Step 2b. Selection of Appropriate Difference Test

From the results of the Kolmogorov-Smirnov Test described above, it was determined that the nonparametric Wilcoxon Matched-Pairs Signed-Ranks Test was the appropriate difference test to apply against these data.

Step 2c. Nonparametric Test for Case 9

This Wilcoxon Test was applied against Case 9 data normalized by both sorties and flying hours. Sorties were considered to be the appropriate measure of system activity. The conclusions reached were therefore based upon the results of tests on data normalized by sorties.

Table 4-2

K-S TEST FOR CASE 9
N = 242

Variable	Critical D_{Max}	Computed D_{Max}	Decision	Conclusion
Fly Hours Before	0.0517	0.0783	Reject	NOT NORMAL
Fly Hours After	"	0.0681	Reject	NOT NORMAL
Sorties Before	"	0.0528	Reject	NOT NORMAL
Sorties After	"	0.0473	Do Not Reject	NORMAL
Maint Actions Before	"	0.1511	Reject	NOT NORMAL
Maint Actions After	"	0.0974	Reject	NOT NORMAL
Maint Hrs. Before	"	0.1457	"	NOT NORMAL
Maint Hrs. After	"	0.1284	"	NOT NORMAL
NORM Hrs. Before	"	0.3446	"	NOT NORMAL
NORM Hrs. After	"	0.4393	"	NOT NORMAL
NORS Hrs. Before	"	0.4959	"	NOT NORMAL
NORS Hrs. After	"	0.5121	"	NOT NORMAL
Failures Before	"	0.1563	"	NOT NORMAL
Failures After	"	0.1476	"	NOT NORMAL

1. Data normalized by sorties. The results of the Wilcoxon statistical hypothesis tests permitted the strong conclusions to be drawn that the mean values of manhours and NORM hours were greater before the modification than after the modification had been accomplished. In addition, the researchers were able to conclude that the mean value of neither maintenance actions, NORS hours, nor failures had increased after the modification. The results of the initial hypothesis tests indicated that the mean value of maintenance actions had either increased or remained the same after the modification. It was therefore necessary to test an hypothesis of the form described in the "Application of Criteria" section of this chapter. The hypothesis test used was:

$$H_0 : \text{MABS} \geq \text{MAAS}$$
$$H_A : \text{MABS} < \text{MHAS}$$

When the null hypothesis (H_0) was tested at the 90 percent confidence level, it was not rejected. It was therefore concluded that maintenance actions after the modification (MAAS) were essentially equal to maintenance actions before the modification (MABS).

2. Data normalized by flying hours. Although sorties were considered the appropriate activity by which the variables should be normalized, analyses of the variables normalized by flying hours were also accomplished. The Wilcoxon Test

results were the same as those obtained from the analyses of variables normalized by sorties except:

a. Maintenance actions increased after the modification.

b. Manhours remained essentially the same after the modification as before.

Step 2d. Parametric Test

The t-Test was also performed because even though the data were not normally distributed, corroboration of the results of the nonparametric test by the parametric t-Test provides additional strength to the nonparametric test results. The conclusions reached by the Wilcoxon Test that manhours and NORM hours were less after the modification than before, were both supported by the t-Test results. Also, the conclusion that maintenance actions were essentially equal before and after the modification was also supported. However, the Wilcoxon Test conclusion that NORS hours were greater before the modification than after was not supported by the findings of the t-Test that there was no statistically significant difference between the NORS hours before and after the modification.

The t-Test results for variables normalized by flying hours were the same as the results obtained from the analysis of variables normalized by sorties except:

1. Maintenance actions increased after the modification.

2. There was no statistically significant difference between failures before and after the modification.

The results of the Wilcoxon Matched-Pairs Signed-Ranks Test, the t-Test, and a comparison of the results of these tests are provided in Tables 4-3, 4-4 and 4-5 respectively.

Step 3. Analyze Test Results

For this modification, it was determined that the number of sorties flown was a better measure of the system activity than flying hours. Therefore, the conclusions reached with the Wilcoxon Test using variable values normalized by sorties were the ones accepted. These conclusions were:

a. The mean value of maintenance hours before the modification was greater than the mean value after the modification.

b. The mean value of NORM hours before the modification was greater than the mean value after the modification.

c. The mean value of no measured variable was greater after the modification than before.

These conclusions were also supported by the conclusions reached using the t-Test on data normalized by sorties.

Table 4-3

WILCOXON TEST FOR CASE 9
$N = 242$
$\alpha = .10$

Variables	Critical Z_{Crit}	Computed Z_S	Decision	Conclusion
Fly Hours	$\pm$ 1.64	-4.61	Reject H_0	FLYB $\neq$ FLYA
Sorties	$\pm$ 1.64	-11.08	Reject H_0	SORB $\neq$ SORA
Maint Actions/Sorties	+ 1.28	-.45	Do Not Reject H_0	MABS $\leq$ MAAS
Maint Hrs/Sorties	- 1.28	-3.97	Reject H_0	MHBS > MHAS
NORM Hrs/Sorties	- 1.28	-6.60	Reject H_0	NORMBS > NORMAS
NORS Hrs/Sorties	- 1.28	-2.13	Reject H_0	NORSBS > NORSAS
Failures/Sorties	- 1.28	-5.53	Reject H_0	FAILBS > FAILAS
Maint Actions/FH	+ 1.28	-5.54	Do Not Reject H_0	MABF $\leq$ MAAF
Maint Hrs/FH	- 1.28	-.7398	Do Not Reject H_0	MHBF $\leq$ MHAF
NORM Hrs/FH	- 1.28	-6.35	Reject H_0	NORMBF > NORMAF
NORS Hrs/FH	- 1.28	-2.04	Reject H_0	NORSBF > NORSAF
Failures/FH	- 1.28	-1.65	Reject H_0	FAILBF > FAILAF

Table 4-4

t-TEST FOR CASE 9
$N = 242$
$\alpha = .10$

Variables	Critical t_{Crit}	Computed t_S	Decision	Conclusion
Fly Hours	± 1.64	-4.32	Reject H_0	FLYB $\neq$ FLYA
Sorties	± 1.64	-14.95	Reject H_0	SORB $\neq$ SORA
Maint Actions/Sorties	1.28	-0.10	Do Not Reject H_0	MABS $\leq$ MAAS
Maint Hrs/Sorties	1.28	4.20	Reject H_0	MHBS > MHAS
NORM Hrs/Sorties	1.28	4.99	Reject H_0	NORMBS > NORMAS
NORS Hrs/Sorties	1.28	0.32	Do Not Reject H_0	NORSBS $\leq$ NORSAS
Failures/Sorties	1.28	5.40	Reject H_0	FAILBS > FAILAS
Maint Actions/FH	1.28	-5.59	Do Not Reject H_0	MABF $\leq$ MAAF
Maint Hrs/FH	1.28	1.40	Reject H_0	MHBF > MHAF
NORM Hrs/FH	1.28	4.82	Reject H_0	NORMBF > NORMAF
NORS Hrs/FH	1.28	0.12	Do Not Reject H_0	NORSBF $\leq$ NORSAF
Failures/FH	1.28	0.94	Do Not Reject H_0	FAILBF $\leq$ FAILAF

Table 4-5

COMPARISON BETWEEN PARAMETRIC AND NONPARAMETRIC TESTS FOR CASE 9
$N = 242$
$\alpha = .10$

Variables	Conclusion		Conclusion Accepted
	Parametric (t-Test)	Nonparametric (Wilcoxon)	
Fly Hours	FLYB ≠ FLYA	FLYB ≠ FLYA	FLYB ≠ FLYA
Sorties	SORB ≠ SORA	SORB ≠ SORA	SORB ≠ SORA
Maint. Actions/Sorties	MABS ≤ MAAS	MABS ≤ MAAS	MABS ≤ MAAS
Maint. Hrs/Sorties	MHBS > MHAS	MHBS > MHAS	MHBS > MHAS
NORM Hrs/Sorties	NORMBS > NORMAS	NORMBS > NORMAS	NORMBS > NORMAS
NORS Hrs/Sorties	NORSBS ≤ NORSAS	NORSBS > NORSAS	NORSBS > NORSAS*
Failures/Sorties	FAILBS > FAILAS	FAILBS > FAILAS	FAILBS > FAILAS
Maint Actions/FH	MABF ≤ MAAF	MABF ≤ MAAF	MABF ≤ MAAF
Maint Hrs/FH	MHBF > MHAF	MHBF ≤ MHAF	MHBF ≤ MHAF*
NORM Hrs/FH	NORMBF > NORMAF	NORMBF > NORMAF	NORMBF > NORMAF
NORS Hrs/FH	NORSBF ≤ NORSAF	NORSBF > NORSAF	NORSBF > NORSAF*
Failures/FH	FAILBF ≤ FAILAF	FAILBF > FAILAF	FAILBF > FAILAF*

*NOTE: Nonparametric and parametric results differ at $\alpha = .10$. Because data are not normally distributed for these variables the conclusion accepted is based on nonparametric test results.

Step 4. Comparison of Statistical Conclusions with Criteria

The analysis of Case 9 showed that when normalized by sorties maintenance hours and NORM hours were less (statistically significant) after the modification than before. In addition, it was concluded that there were no statistically significant increases in the mean value of other measured variables when normalized by sorties. In fact, it was concluded that NORS hours and failures were also less (statistically significant) after the modification than before. Furthermore, there was shown to be no statistically significant difference between maintenance actions before and after the modification.

Step 5. Effectiveness Conclusion

Modification F65D87B (Case 9) was considered to be effective in providing improved logistics support.

ANALYSIS OF THIRTEEN OTHER CASES

The following discussion explains in an abbreviated manner the application of the technique to thirteen other modifications. These modifications were selected to demonstrate the use of the technique on what is assumed to be a representative sample of typical Class IV modifications. As explained earlier, the first five modifications do not include data on availability (i.e., NORM or NORS), and have only six months of data accumulated as opposed to 18 months for the other nine cases.

Step 1. Criteria

The criteria utilized in evaluating the effectiveness of these 13 modifications are identical to those used in evaluating Case 9. The AFLC Forms 48 were not available for review by the researchers on Cases 1-6. These cases were initially selected by other individuals. In the first five cases, the purpose of the specific modification was obtained from a draft copy of Mitchell and Carter's study (20) of the modifications. The purpose of Case 6 was obtained from personnel assigned at San Antonio ALC. In the other cases, the researchers had obtained copies of the original AFLC Form 48 to determine the modifications' purpose.

Step 2a. Determination of Data Distribution

The K-S program was used to evaluate the data to determine which sets of data were normally distributed. In all thirteen cases the only data that were normally distributed were those associated with equipment activity, i.e., flying hours and sorties. None of the variables associated with equipment reliability, maintainability, or availability followed a normal distribution.

Step 2b. Selection of Appropriate Difference Test

From the results of the K-S test the parametric Paired t-Test could only be used by itself in seven instances to determine the direction of change in the mean

value of the variable being analyzed at a 90 percent confidence level. In the other 129 instances, the nonparametric Wilcoxon Matched-Pairs Signed-Ranks Test became the primary method for testing the statistical hypotheses.

Step 2c. Nonparametric Test

Since the majority of the data were not normally distributed, the nonparametric Wilcoxon Test became the appropriate method to test our hypotheses in 129 out of 136 instances. The hypotheses accepted from these tests are shown in Table 4-6. The relationship or direction of change between the paired variables tested (before compared to after) is shown in the table. If the final hypothesis accepted is the same as that indicated in the left hand column, then a "YES" appears in the appropriate location in the table.

Step 2d. Parametric Test

Every set of data for these 13 modifications were analyzed with the SPSS t-Test program. In only one instance out of 136 tests did the t-Test not support the statistical hypotheses concluded from the nonparametric Wilcoxon Test. This difference occurred in Case 7 where the t-Test indicated at $\alpha = .10$ that NORSBS $\leq$ NORSAS. The Wilcoxon Test proved the alternate hypothesis at $\alpha = .10$ that NORSBS > NORSAS. However, because the data for NORSBS and NORSAS were not normally distributed, it had

Table 4-6

SUMMARY OF CONCLUSIONS ACCEPTED
$\alpha = .10$

Hypotheses Tested \ Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLYB = FLYA	YES	YES	≠	YES	YES	≠	≠	≠	≠	≠	YES	YES	YES	≠
SORB = SORA	YES	≠	≠	YES	≠	≠	≠	≠	≠	≠	≠	≠	≠	≠
MABS > MAAS	≤	YES	≤	YES	≤	≤	≤	≤	=	YES	YES	≤	≤	≤
MHBS > MHAS	≤	YES	≤	YES	≤	≤	≤	≤	YES	YES	YES	≤	≤	≤
NORMBS > NORMAS	N/A	N/A	N/A	N/A	N/A	≤	≤	≤	YES	=	YES	YES	≤	≤
NORSBS > NORSAS	N/A	N/A	N/A	N/A	N/A	≤	YES	≤	YES	=	YES	≤	≤	≤
FAILBS > FAILAS	≤	YES	≤	YES	≤	≤	≤	≤	YES	YES	YES	≤	≤	≤
MABF > MAAF	≤	YES	≤	=	≤	≤	≤	≤	<	YES	YES	≤	≤	≤
MHBF > MHAF	≤	YES	≤	=	≤	≤	≤	≤	=	YES	YES	≤	≤	≤
NORMBF > NORMAF	N/A	N/A	N/A	N/A	N/A	≤	≤	≤	YES	=	YES	YES	≤	≤
NORSBF > NORSAF	N/A	N/A	N/A	N/A	N/A	≤	=	≤	YES	=	YES	≤	≤	≤
FAILBF > FAILAF	≤	YES	≤	YES	≤	≤	≤	≤	YES	YES	YES	≤	≤	≤

to be concluded that NORSBS > NORSAS since the parametric t-Test could not be employed in this paired analysis. In all the other 135 conclusions the nonparametric Wilcoxon Test was supported by the parametric t-Test which provided additional strength to the nonparametric test results.

Step 3. Analyze Test Results

The conclusions from the appropriate differences test were used to determine the changes that occurred in the test variables. Some additional analyses needed to be performed in some cases to determine the effect of the modification. For example, in Case 4 maintenance actions and manhours normalized by sorties were shown by the Wilcoxon Test to have decreased after the modification. However, the null hypotheses (before $\leq$ after) were not rejected for these two variables when the data were normalized by flying hours. Because of this difference in statistical conclusions, it became necessary to determine whether the variables MAAF and MHAF actually had been increased by the modification or had remained unchanged. It was determined at a 90 percent confidence level that the mean value of these two variables (maintenance actions and manhours) had not increased after the modification.

A similar test had to be performed for Case 7. In Case 7 the following conclusions were obtained after additional testing:

a. NORSBS > NORSAS

b. NORSBF = NORSAS

Therefore, it could be concluded that NORS time had not been increased by the modification.

Step 4. Comparison of Statistical Conclusions with Criteria

The results of this comparison are shown in Table 4-7. The variables selected for comparison are based on the stated purpose as indicated on the AFLC Form 48 and the relationships previously established in this study.

Step 5. Effectiveness Conclusion

In these thirteen cases, four modifications were determined to be effective. The effectiveness of the modifications is shown in Table 4-7.

It should be noted that any variables that were decreased after the modification but were not included as part of the stated purpose of the modification were considered irrelevant in determining the effectiveness of the modification. This occurred in Case 12 when NORM time (normalized by sorties and flying hours) was shown to decrease after the modification. The purposes as stated on the AFLC Form 48 of the modification were to prevent failures and "more expensive repair actions." The analyses showed that maintenance actions and failures had not decreased after the modification. Therefore, the modification

Table 4-7

SUMMARY OF MODIFICATION EFFECTIVENESS

CASE NO.	PURPOSE EVALUATED	KEY VARIABLE(S)	ANALYSIS RESULTS	EFFECTIVENESS CONCLUSION
1	*Increase Reliability	Failures	Failures Not Reduced	MOD. Not Effective
2	*Reduce Failures	Failures	Failures Reduced	MOD. Was Effective
3	*Increase Reliability	Failures	Failures Not Reduced	MOD. Not Effective
4	*Increase Reliability	Failures	Failures Reduced	MOD. Was Effective
5	*Increase Reliability	Failures	Failures Not Reduced	MOD. Not Effective
6	*Reduce Manhours	Maint. Hrs.	Maint. Hrs. Not Reduced	MOD. Not Effective
7	Reduce Failures Reduce NORS	Failures NORS	Failures Not Reduced NORS Reduced	MOD. Not Effective
8	Reduce Failures Reduce NORS	Failures NORS	Failures Not Reduced NORS Not Reduced	MOD. Not Effective
9	Reduce Manhours and NORM	Maint. Hrs. NORM	Maint. Hrs. Reduced NORM Reduced	MOD. Was Effective
10	*Reduce Failures and Manhours	Failures Maint. Hrs.	Failures Reduced Maint. Hrs. Reduced	MOD. Was Effective.
11	Reduce Failures, Manhours, NORS, NORM	Failures, Maint. Hrs., NORS & NORM	All Measured Variables Reduced	MOD. Was Effective
12	*Reduce Maint. Actions And Failures	Maint. Actions and Failures	Maint. Actions/Failures Not Reduced	MOD. Not Effective
13	*Reduce Failures	Failures	Failures Not Reduced	MOD. Not Effective
14	*Reduce Failures	Failures	Failures Not Reduced	MOD. Not Effective

*Secondary Purpose

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DEVELOPMENT OF A SYSTEMATIC TECHNIQUE FOR ANALYZING THE EFFECTI--ETC(U)
SEP 78 C J COLEMAN, T R EDISON

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did not accomplish its intended purpose and was considered not effective. The change in NORM time had no effect on this conclusion and was not considered.

RESULTS OF ANALYSIS OF DATA

Of the fourteen modifications selected, five were determined to be effective when evaluated by the developed technique. The following is a summary of the effective modifications:

Table 4-8

SUMMARY OF EFFECTIVE MODIFICATIONS

CASE NO.	TYPE	
2	IVA	Reduction in all measured variables*
4	IVB	Reduction in MAS, MHS, FAILS, & FAILF*
9	IVB	Reduction in MHS, NORMS, NORMF, NORSS, NORSF, NORMS, NORMF, FAILS, FAILF
10	IVB	Reduction in MAS, MAF, MHS, MHF, FAILS, & FAILF
11	IVC	Reduction in all measured variables

*NORM & NORS variables not measured.

It should be noted that only one out of the three Class IVC modifications selected for evaluation actually achieved their stated purpose of reducing logistic support.

The specific data analyzed and the computer print-outs for this study are available for review at AFALD/XRSC, Wright-Patterson AFB. Typical examples of the K-S, Wilcoxon, and t-Test programs used are provided in Appendices C, D, and E, respectively.

SUMMARY

This chapter provided a detailed discussion of the analyses completed on Case 9 using the technique developed in Chapter 3. Each step in the proposed technique was explained using the data analyses accomplished in this case. The results of the tests performed on the other 13 cases were also described. Finally, a summary was provided of those modifications that were shown to be effective after the testing had been completed.

Chapter 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

In this chapter the initial discussion will provide a summary of the research performed. This will be followed by a presentation of the resulting conclusions of the research. The final discussions will describe some recommendations for additional research effort.

SUMMARY

This study has shown that for many years the Air Force has been approving Class IV modifications to reduce aircraft logistic support requirements and improve aircraft reliability, maintainability, and availability. While there are extensive reviews by Configuration Control Boards prior to their approval, no systematic technique exists for assessment of the modifications after implementation to evaluate their effectiveness in achieving their stated purposes.

Using data from the Air Force G098 system, an assessment technique was developed in this study which used parametric and nonparametric statistical mean difference tests to evaluate the effectiveness of Class IV modifications.

Fourteen selected modifications were evaluated to demonstrate how the G098 data were compiled and analyzed by this technique. Included in this evaluation were data on maintenance actions, manhours, NORM, NORS, and failures before and after the modification. These data sets were adjusted for variations in flying hours and sorties. The data were then analyzed to determine if there were any significant improvements as a result of the Class IV modification. A modification was determined to be effective if these improvements were part of the original stated purpose of the modification as indicated on the AFLC Form 48.

The following research question as previously stated, was answered in the affirmative: Can a systematic technique which uses available systems data be developed to determine whether or not the stated purposes appearing on the AFLC Form 48 as part of the original justification for Class IV modifications have been achieved?

CONCLUSIONS

Conclusion 1

Data are available in several Air Force data systems which can be used as the basis of a technique for evaluating the effectiveness of aircraft modifications designed to improve logistics support. The Configuration Control Board Item Records (AFLC Form 48) can be used as the source of

data concerning the purpose of, and items affected by, the modifications. The Standard Configuration Management System (D047) and the Advanced Configuration Management System (D057G) can provide information concerning the aircraft serial numbers affected by a modification and the date each individual serial number was modified. The Maintenance Requirements Data System (G098) can be used as the source of aircraft maintenance, inventory, utilization, and status information by aircraft serial number. The combination of the above data sources provide the data necessary for development of a technique for assessing the impact of a modification on logistics support of an aircraft.

Conclusion 2

The parametric t-Test and the nonparametric Wilcoxon Matched-Pairs Signed-Ranks Test are difference tests which provide viable methods for comparing the mean values of variables before and after a modification. Computerized application of these tests to appropriately matched data allow conclusions to be derived regarding increases/ decreases in the mean values of the variables represented by the data.

Conclusion 3

The technique developed in this study can be used, under the conditions indicated, for evaluating the effectiveness of Class IV modifications in reducing aircraft logistics support requirements.

Conclusion 4

It was not possible to conclude from this study which measure of activity (flying hours or sorties) was a better indicator of aircraft system activity. Instead it was concluded that the researcher must evaluate the activity measure to be used on a case-by-case basis. This evaluation will be somewhat subjective. Additionally, the degree of confidence placed on the conclusions derived will depend to some extent upon the experience of the researcher and his familiarity with the system being studied.

RECOMMENDATIONS

Recommendation 1

Additional effort should be expended to apply this analytical technique to other aircraft modifications. Modifications on other mission, design, or series (MDS) aircraft should be evaluated by this technique.

Recommendation 2

The technique should be assessed to determine its applicability to the assessment of the impact of changes, other than Class IV modification, on logistics support. Examples of such changes which might be assessed using this technique are:

1. Class I Modifications,
2. Class V Modifications, and
3. Phase Inspections.

Recommendation 3

Research should continue to be conducted on efforts to develop a method of costing improvements resulting from modifications. This would allow computation of dollar benefits resulting from modifications.

Appendix A

Appendix A

ABBREVIATIONS

FLYB---Flying hours per aircraft during the period preceding a modification.

FLYA---Flying hours per aircraft during the period following a modification.

SORB---Sorties per aircraft during the period preceding a modification.

SORA---Sorties per aircraft during the period following a modification.

MAB----Maintenance actions per aircraft on the modified equipment during the period preceding a modification.

MAA----Maintenance actions per aircraft on the modified equipment during the period following a modification.

MABF---MAB divided by FLYB.

MAAF---MAA divided by FLYA.

MABS---MAB divided by SORB.

MAAS---MAA divided by SORA.

MHB----Manhours per aircraft expended to repair the modified equipment during the period preceding a modification.

MHA----Manhours per aircraft expended to repair the modified equipment during the period following a modification.

MHBF---MHB divided by FLYB.

MHAF---MHA divided by FLYA.

MHBS---MHB divided by SORB.

MHAS---MHA divided by SORA.

FAILB--Failures per aircraft of the modified equipment during the period preceding a modification.

FAILA----Failures per aircraft of the modified equipment during the period following a modification.

FAILBF---FAILB divided by FLYB.

FAILAF---FAILA divided by FLYA.

FAILBS---FAILB divided by SORB.

FAILAS---FAILA divided by SORA.

NORMB----Not Operationally Ready due to Maintenance hours per aircraft on the modified equipment during the period preceding a modification.

NORMA----Not Operationally Ready due to Maintenance hours per aircraft on the modified equipment during the period following a modification.

NORMBF---NORMB divided by FLYB.

NORMAF---NORMA divided by FLYA.

NORMBS---NORMB divided by SORB.

NORMAS---NORMA divided by SORA.

NORSB----Not Operationally Ready due to Supply hours per aircraft on the modified equipment during the period preceding a modification.

NORSA----Not Operationally Ready due to Supply hours per aircraft on the modified equipment during the period following a modification.

NORSBF---NORSB divided by FLYB.

NORSAF---NORSA divided by FLYA.

NORSBS---NORSB divided by SORB.

NORSAS---NORSB divided by SORA.

Appendix B

Appendix B

GLOSSARY OF TERMS

Availability: The probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon [3:5].

Logistic Support: Includes such items as test and support equipment, supply support (spares and repair parts), personnel and training, technical data, facilities, transportation and handling, and maintenance planning (3:8-9).

Maintainability: A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources [3:10].

Reliability: The probability that a system or product will give satisfactory performance for a specified period of time when used under stated conditions . . . . Reliability can be expressed in terms of mean time between failures (MTBF) or mean life [3:12].

Supportability: Considers maintenance time, logistic resources, and maintenance cost [3:19].

Appendix C

Appendix C

K-S PROGRAM

```
10SAMPLE OF PROGRAM USED FOR K-S TEST
20TRE14,CM120000,T20,IO20,STCSB.  T770253,EDISON/COLEMAN,56513
30ATTACH,SPSS7,ID=AFIT.
40SPSS7.
50 7/8/9
60RUN NAME          K-S TEST FOR MOD 14
70VARIABLE LIST     MO,SN,FLYB,FLYA,SORB,SORA,MAB,MAA,MHB,MHA,
80                  NORMB,NORMA,NORSB,NORSA,FAILB,FAILA
90INPUT FORMAT      FIXED(F2.0,F8.0,2F5.1,4F4.0,6F5.1,2F4.0)
100N OF CASES       335
110COMPUTE          MABS=MAB/SORB
120COMPUTE          MAAS=MAA/SORA
130COMPUTE          MHBS=MHB/SORB
140COMPUTE          MHAS=MHA/SORA
150COMPUTE          NORMBS=NORMB/SORB
160COMPUTE          NORMAS=NORMA/SORA
170COMPUTE          NORSBS=NORSB/SORB
180COMPUTE          NORSAS=NORSA/SORA
190COMPUTE          FAILBS=FAILB/SORB
200COMPUTE          FAILAS=FAILA/SORA
210COMPUTE          MABF=MAB/FLYB
220COMPUTE          MAAF=MAA/FLYA
230COMPUTE          MHBF=MHB/FLYB
240COMPUTE          MHAF=MHA/FLYA
250COMPUTE          NORMBF=NORMB/FLYB
260COMPUTE          NORMAF=NORMA/FLYA
270COMPUTE          NORSBF=NORSB/FLYB
280COMPUTE          NORSAF=NORSA/FLYA
290COMPUTE          FAILBF=FAILB/FLYB
300COMPUTE          FAILAF=FAILA/FLYA
310NPAR TESTS       K-S(NORMAL)=FLYB/K-S(NORMAL)=FLYA/K-S
320                 (NORMAL)=SORB/K-S(NORMAL)=SORA/K-S(NORMAL)=MABF/
330                 K-S(NORMAL)=MAAF/K-S(NORMAL)=MHBF/K-S(NORMAL)=
340                 MHAF/K-S(NORMAL)=NORMBF/K-S(NORMAL)=NORMAF/K-S
350                 (NORMAL)=NORSBF/K-S(NORMAL)=NORSAF/K-S(NORMAL)
360                 =FAILBF/K-S(NORMAL)=FAILAF/K-S(NORMAL)=MABS/K-S(
370                 NORMAL)=MAAS/K-S(NORMAL)=MHBS/K-S(NORMAL)=MHAS/
380                 K-S(NORMAL)=NORMBS/K-S(NORMAL)=NORMAS/K-S(NORMAL)
390                 =NORSBS/K-S(NORMAL)=NORSAS/K-S(NORMAL)=FAILBS/
400                 K-S(NORMAL)=FAILAS/K-S(NORMAL)=MAB/K-S(NORMAL)=
410                 MAA/K-S(NORMAL)=MHB/K-S(NORMAL)=MHA/K-S(NORMAL)=
420                 NORMB/K-S(NORMAL)=NORMA/K-S(NORMAL)=NORSB/
430                 K-S(NORMAL)=NORSA/K-S(NORMAL)=FAILB/K-S(NORMAL)
440                 =FAILA
450OPTIONS          3
460READ INPUT DATA
470FINISH
```

Appendix D

Appendix D

WILCOXON PROGRAM

```
100SAMPLE OF PROGRAM USED FOR WILCOXON TEST
110TRE12,CM120000,T20,IO20,STCSB.  T770253,EDISON/COLEMAN,56513
120ATTACH,SPSS7,ID=AFIT.
130SPSS7.
140 7/8/9
150RUN NAME         WILCOXON TEST MOD12
160VARIABLE LIST    MO,SN,FLYB,FLYA,SORB,SORA,MAB,MAA,MHB,MHA,
170                 NORMB,NORMA,NORSB,NORSA,FAILB,FAILA
180INPUT FORMAT     FIXED(F2.0,F8.0,2F5.1,4F4.0,6F5.1,2F4.0)
190N OF CASES       265
200COMPUTE          MABS=MAB/SORB
210COMPUTE          MAAS=MAA/SORA
220COMPUTE          MHBS=MHB/SORB
230COMPUTE          MHAS=MHA/SORA
240COMPUTE          NORMBS=NORMB/SORB
250COMPUTE          NORMAS=NORMA/SORA
260COMPUTE          NORSBS=NORSB/SORB
270COMPUTE          NORSAS=NORSA/SORA
280COMPUTE          FAILBS=FAILB/SORB
290COMPUTE          FAILAS=FAILA/SORA
300COMPUTE          MABF=MAB/FLYB
310COMPUTE          MAAF=MAA/FLYA
320COMPUTE          MHBF=MHB/FLYB
330COMPUTE          MHAF=MHA/FLYA
340COMPUTE          NORMBF=NORMB/FLYB
350COMPUTE          NORMAF=NORMA/FLYA
360COMPUTE          NORSBF=NORSB/FLYB
370COMPUTE          NORSAF=NORSA/FLYA
380COMPUTE          FAILBF=FAILB/FLYB
390COMPUTE          FAILAF=FAILA/FLYA
400NPAR TESTS       WILCOXON=FLYB,SORB,MAB,MHB,NORMB,NORSB,
410                 FAILB,MABS,MHBS,NORMBS,NORSBS,FAILBS,
420                 MABF,MHBF,NORMBF,NORSBF,FAILBF WITH
430                 FLYA,SORA,MAA,MHA,NORMA,NORSA,FAILA,
440                 MAAS,MHAS,NORMAS,NORSAS,FAILAS,MAAF,
450                 MHAF,NORMAF,NORSAF,FAILAF
460OPTIONS          3
470READ INPUT DATA
480FINISH
```

Appendix E

Appendix E

t-TEST PROGRAM

```
$       IDENT   WP1149,AFIT/LSG COLEMAN EDISON 78B
$       SELECT*SPSS/BIGSPSS
RUN NAME        PAR T-TEST,NORMALIZED BY FLY HRS. & SORTIES-MOD12
COMMENT         THIS PROGRAM PERFORMS THE PARAMETRIC T-TEST
                DESCRIBED IN THE STUDY
VARIABLE LIST   MO,SN,FLYB,FLYA,SORB,SORA,MAB,MAA,MHB,MHA,
                NORMB,NORMA,NORSB,NORSA,FAILB,FAILA
INPUT FORMAT    FIXED(F2.0,F8.0,2F5.1,4F4.0,6F5.1,2F4.0)
INPUT MEDIUM    CARD
ALLOCATE        TRANSPACE=5000
N OF CASES      265
COMMENT         THE FOLLOWING COMPUTATIONS ARE REQUIRED TO
                REMOVE THE EFFECTS OF FLYING HOURS AND/OR
                SORTIES PRIOR TO PERFORMING THE T-TEST
COMPUTE         MABF=MAB/FLYB
COMPUTE         MAAF=MAA/FLYA
COMPUTE         MHBF=MHB/FLYB
COMPUTE         MHAF=MHA/FLYA
COMPUTE         NORMBF=NORMB/FLYB
COMPUTE         NORMAF=NORMA/FLYA
COMPUTE         NORSBF=NORSB/FLYB
COMPUTE         NORSAF=NORSA/FLYA
COMPUTE         FAILBF=FAILB/FLYB
COMPUTE         FAILAF=FAILA/FLYA
COMPUTE         MABS=MAB/SORB
COMPUTE         MAAS=MAA/SORA
COMPUTE         MHBS=MHB/SORB
COMPUTE         MHAS=MHA/SORA
COMPUTE         NORMBS=NORMB/SORB
COMPUTE         NORMAS=NORMA/SORA
COMPUTE         NORSBS=NORSB/SORB
COMPUTE         NORSAS=NORSA/SORA
COMPUTE         FAILBS=FAILB/SORB
COMPUTE         FAILAS=FAILA/SORA
COMMENT         THE T-TEST WAS PERFORMED ON ALL BEFORE AND
                AFTER DATA PAIRS SO RESULTS COULD BE COMPARED
                WITH NON-PARAMETRIC TEST RESULTS
T-TEST          PAIRS=FLYB,FLYA/SORB,SORA/MAB,MAA/MHB,MHA/
                NORMB,NORMA/NORSB,NORSA/FAILB,FAILA/
                MABF,MAAF/MHBF,MHAF/NORMBF,NORMAF/NORSBF,
                NORSAF/FAILBF,FAILAF/MABS,MAAS/MHBS,MHAS/
                NORSBS,NORSAS/FAILBS,FAILAS
READ INPUT DATA
$       SELECTA MOD12
FINISH
$       ENDJOB
```

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